Hazard Profile - Earthquake

Introduction[1, 2]

An earthquake is the sudden release of stored energy; most earthquakes occur along a fracture within the earth, called a fault. The shaking caused by this sudden shift is often very small, but occasionally large earthquakes produce very strong ground shaking. It is this strong shaking and its consequences – ground failure, landslides, liquefaction – that damages buildings and structures and upsets the regional economy.

Washington, especially the Puget Sound basin, has a history of frequent earthquakes. More than 1,000 earthquakes occur in the state each year. A dozen or more are strong enough that people feel ground shaking; occasionally, earthquakes cause damage. Large earthquakes in 1946 (magnitude 5.8), 1949 (magnitude 7.1) and 1965 (magnitude 6.5) killed 15 people and caused more than $200 million (1984 dollars) in damage throughout several counties. The state experienced at least 20 damaging events in the last 125 years.

The Nisqually earthquake on February 28, 2001, was a deep, magnitude 6.8 earthquake 10 miles northeast of Olympia. One person died of a heart attack, more than 700 people were injured, and various estimates place damage at between $1 billion and $4 billion; exact figures are not available, as insurance claims information is not available.

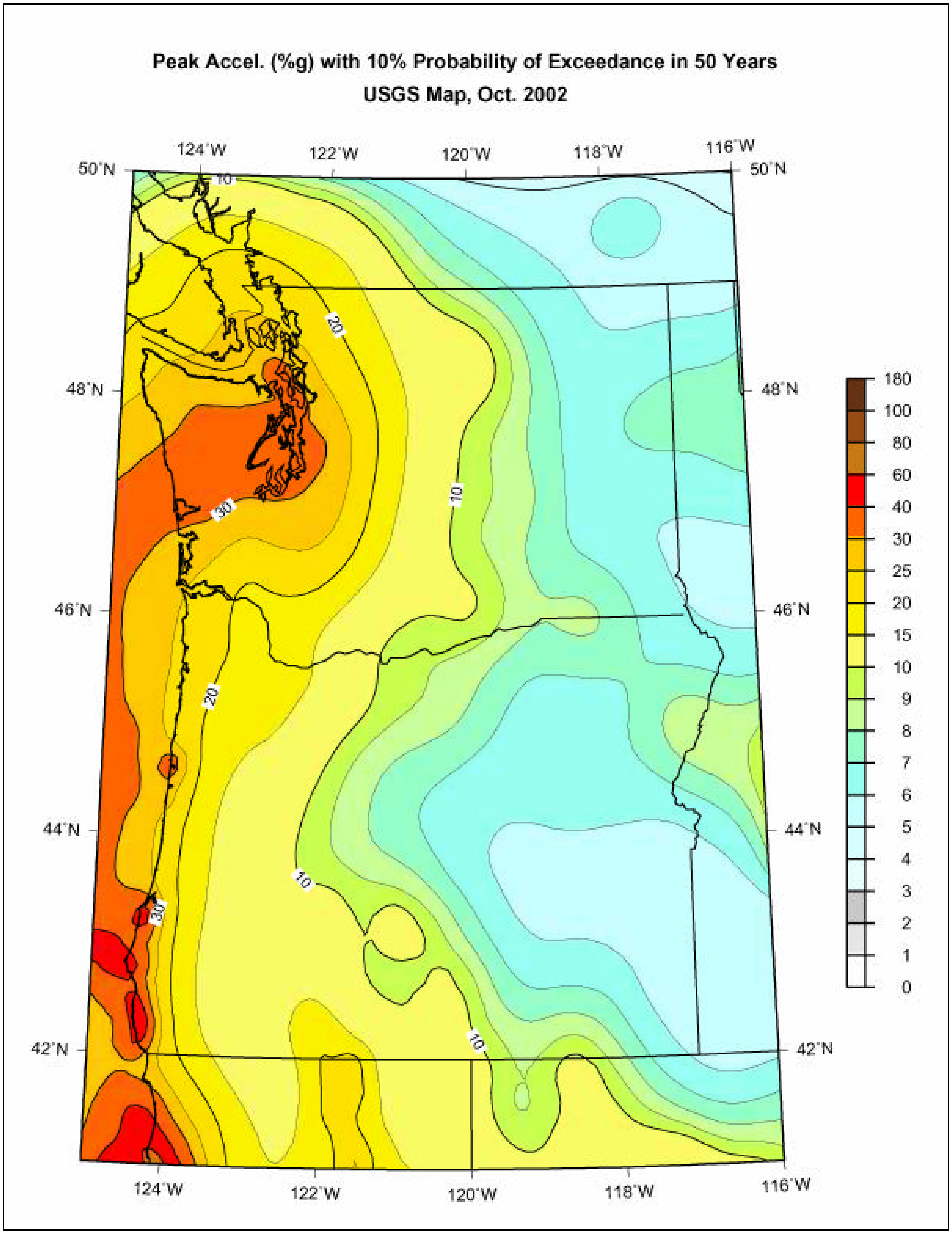
The earthquake threat in Washington is not uniform; see peak ground shaking probability for a 500-year earthquake graphic, page 2. While most earthquakes occur in Western Washington, some damaging events, such as the 1872 magnitude 6.8 (est.) quake, do occur east of the Cascades. Geologic evidence documents prehistoric magnitude 8 to 9.5 earthquakes along the outer coast, and events of magnitude 7 or greater along shallow crustal faults in the urban areas of Puget Sound.

Washington's earthquake hazards reflect its tectonic setting. The Pacific Northwest is at a convergent continental margin, the collision boundary between two tectonic plates of the Earth's crust. The Cascadia subduction zone, the fault boundary between the North America plate and the Juan de Fuca plate, lies offshore from northern California to southern British Columbia. The two plates are converging at a rate of about 2 inches per year. In addition, the northward-moving Pacific plate is pushing the Juan de Fuca plate north, causing complex seismic strain to accumulate. The abrupt release of this slowly accumulated strain causes earthquakes.

As a result of the subduction process, the state is vulnerable to earthquakes originating from three sources: in the subducting plate (called an Intraplate or Benioff Zone quake); between the colliding plates (Subduction Zone quake); and in the overriding plate (Shallow Crustal quake).

Intraplate or Benioff Zone Earthquakes[3]

Intraplate or Benioff Zone earthquakes occur within the subducting Juan de Fuca plate at depths of 15 to 60 miles, although the largest events typically occur at depths of



Reds = More severe ground shaking. Blues, greens = Less severe ground shaking.

Source: U.S. Geological Survey Earthquake Hazards Program, http://eqhazmaps.usgs.gov/2002October/PN/PNpga500v3.pdf.

about 25 to 40 miles. The largest recorded event was the magnitude 7.1 Olympia quake in 1949. Other significant Benioff zone events include the magnitude 6.5 Seattle-Tacoma quake in 1965, the magnitude 5.8 Satsop quake in 1999, and the magnitude 6.8 Nisqually quake of 2001. Strong shaking during the 1949 Olympia earthquake lasted about 20 seconds; during the 2001 Nisqually earthquake, about 15 to 20 seconds.

Since 1900, there have been five earthquakes in the Puget Sound basin with measured or estimated magnitude of 6 or larger, and one of magnitude 7.

The probability of future occurrence for earthquakes similar to the 1965 magnitude 6.5 Seattle-Tacoma event and the 2001 magnitude 6.8 Nisqually event is about once every 35 years. The approximate recurrence rate for earthquakes similar to the 1949 magnitude 7.1 Olympia earthquake is once every 110 years.

Subduction Zone (Interplate) Earthquakes[4]

Subduction zone or interplate earthquakes occur along the interface between tectonic plates. Scientists have found evidence of great-magnitude earthquakes along the Cascadia Subduction Zone. These earthquakes are very powerful, with a magnitude of 8 to 9 or greater; they have occurred at intervals ranging from every 100 years to every 1,100 years. The last of these great earthquakes struck Washington in 1700. Scientists currently estimate that a magnitude 9 earthquake in the Cascadia Subduction Zone occurs about once every 350 to 500 years.[5]

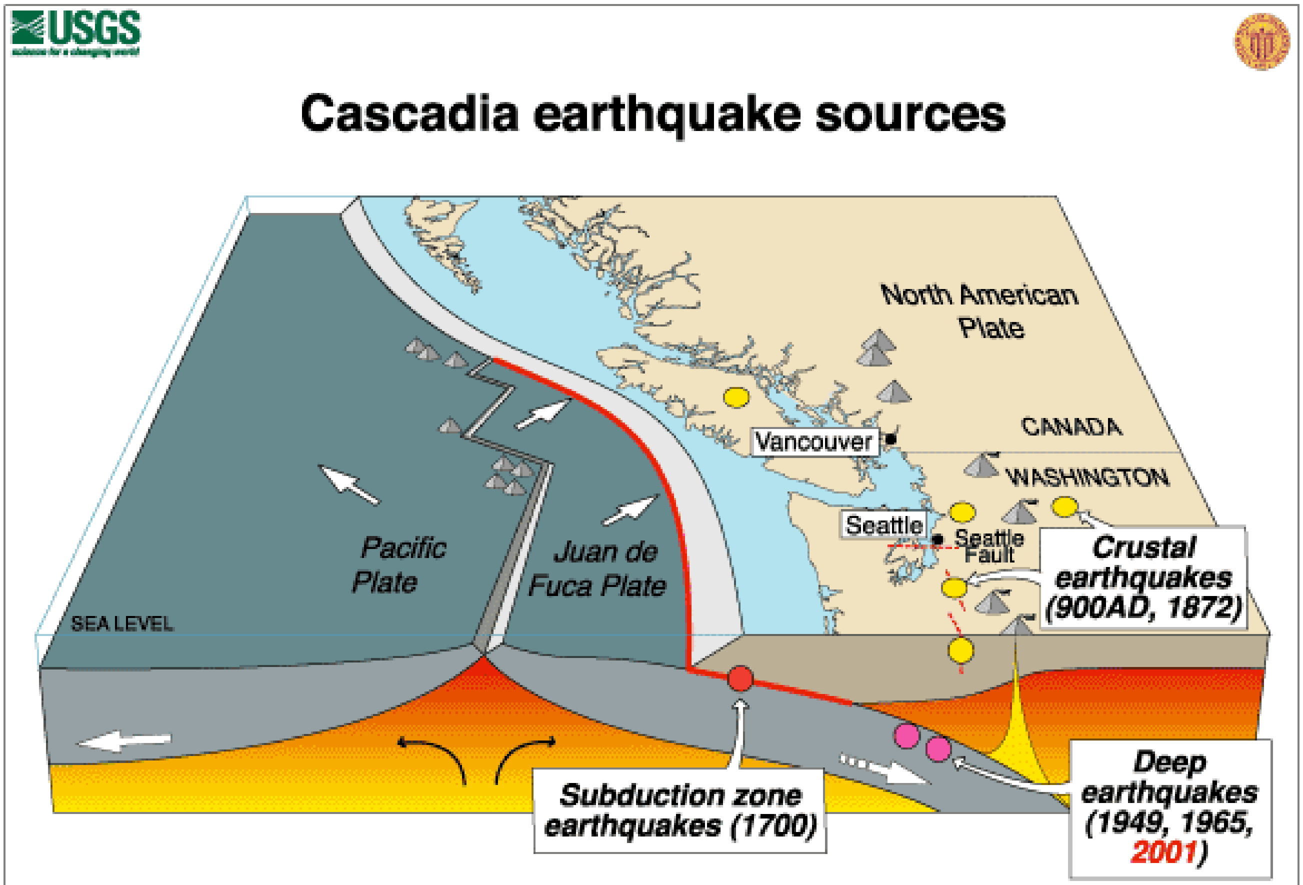
Shallow Crustal Earthquakes[6]

Shallow crustal earthquakes occur within about 20 miles of the surface. Recent examples occurred near Bremerton in 1997, near Duvall in 1996, off Maury Island in 1995, near Deming in 1990, near North Bend in 1945, just north of Portland in 1962, and at Elk Lake on the St. Helens seismic zone (a fault zone running north-northwest through Mount St. Helens) in 1981. These earthquakes had a magnitude of 5 to 5.5.

Scientists believe the 1872 magnitude 6.8 earthquake near Lake Chelan was shallow, and may be the state's most widely felt earthquake. The 1936 magnitude 6.1 earthquake near Walla Walla also was shallow. Because of their remote locations and the relatively small population in the region, though, damage was light from these two quakes.

Scientists continue to study known surface faults, with recurrence rates for earthquakes on some faults estimated. Four magnitude 7.0 or greater events occurred during the past 1,100 years, including two since 1918 on Vancouver Island.

The findings of ongoing research on surface faults (see below) may lead to an assessment of greater earthquake risk in Washington than currently perceived.



Source	Affected area	Max. Size	Recurrence
Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

Puget Lowland [7, 8, 9, 10, 11]

Recent studies have greatly enhanced scientists' ability to locate and study active faults. These studies have uncovered at least seven active faults in the Puget Lowland capable of generating damaging earthquakes. The faults include the Seattle fault, Tacoma fault, Darrington-Devils Mountain fault, Utsalady Point fault, and the Southern Whidbey Island fault.

The Puget Lowland faults are of particular concern, as much of the area is heavily urbanized and populated. According to the 2000 Census, the four-county (King, Kitsap, Pierce and Snohomish) central Puget Sound area where a number of the faults are found, is home to more than 3.2 million people, about 60 percent of the state's population, and much of the state's economic base.

While investigation continues on Puget Lowland faults, scientists already have learned much about them. For example, evidence points to a magnitude 7 or greater earthquake on the Seattle fault about 900 A.D. Such evidence includes a tsunami deposit in Puget Sound, landslides in Lake Washington, rockslides on nearby mountains, and a seven-meter uplift of a marine terrace.

An earthquake with such a magnitude today would cause tremendous damage and economic disruption throughout the central Puget Sound region. Preliminary estimates of damage and loss developed for a multi-disciplinary group preparing a scenario for a magnitude 6.7 event on the fault showed such a quake would result in extensive or complete damage to more than 58,000 buildings with a loss of $36 billion, more than 55,000 displaced households, and up to 2,400 deaths and 800 injuries requiring hospitalization.

Scientists currently estimate the approximate recurrence rate of a magnitude 6.5 or greater earthquake on the Seattle Fault at about once every 1,000 years.

Recent research also indicates the Darrington-Devils Mountain fault appears capable of generating an earthquake of magnitude 7.5, while the Southern Whidbey Fault appears capable to generating earthquakes of magnitude 7 or greater.

Geologists are continuing to study Puget Lowland faults, and have not yet determined recurrence intervals for earthquakes generated for all known faults. However, scientists currently believe that a shallow earthquake of magnitude 6.5 or greater on one of the Puget Lowland faults occurs about once every 333 years.

<u>Eastern Washington</u>[12, 13, 14]

The state's two largest crustal earthquakes felt by European settlers occurred in Eastern Washington – the 1872 quake near Lake Chelan and the 1936 earthquake near Walla Walla. Residents of Spokane strongly felt a swarm of earthquakes in 2001; the largest earthquake in the swarm had a magnitude of 4.0.

The recent Spokane earthquakes were very shallow, with most events located within a few miles of the surface. The events occurred near a suspected fault informally called the Latah Fault; however, the relation between the fault and the swarm is uncertain. Geologists have mapped the Spokane area, but none confirmed the presence of major faults that might be capable of producing earthquakes. State geologists continue to investigate the geology and earthquake risk in Spokane.

Elsewhere in Eastern Washington, geologists have uncovered evidence of a number of surface faults; however, they have not yet determined how active the faults are, nor determined the extent of the risk they pose to the public. One fault, Toppenish Ridge, appears to have been the source of two earthquakes with magnitudes of 6.5 to 7.3 in the past 10,000 years.

Predicting Earthquakes[15]

The size of a fault segment, the stiffness of rocks, and the amount of accumulated stress control the magnitude and timing of earthquakes. Fault segments most likely to break can be identified where faults and plate motions are well known.

If a fault segment is known to have broken in a past large earthquake, recurrence time and probable magnitude can be estimated based on fault segment size, rupture history, and accumulation of strain. Such a forecast, however, can be used only for well-understood faults, such as the San Andreas fault in California. No such forecasts can be made of poorly understood fault.

Faults in the Pacific Northwest are complex, and research on them is continuing. It is not yet possible to forecast when any particular fault segment in Washington State will break.

Earthquake Effects

Earthquakes cause damage by strong ground shaking and by the secondary effects of ground failures, tsunamis, and seiches. The strength of ground shaking generally decreases with distance from the earthquake source. Shaking can be much higher when soft soils amplify earthquake waves. West Seattle and downtown Olympia are examples where amplification repeatedly has occurred and ground shaking was much stronger than in other nearby areas.

Ground failures caused by earthquakes include fault rupture, ground cracking, lateral spreading, slumps, landslides, rock falls, liquefaction, uplift and subsidence. Faults often do not rupture through to the surface. Unstable or unconsolidated soil is most at risk. Any of these failures will affect structures above or below them.

Earthquakes can cause large and disastrous landslides. Liquefaction, which occurs when water-saturated soil shake so violently that it loses its strength, causes building foundations to fail and low-density structures such as underground fuel tanks and piling to float.

Tsunamis are waves that result from the displacement of the water column by changes in the sea floor, by landslides or submarine slides, or by volcanic explosions in the water. Seiches are standing waves in an enclosed or partially enclosed body of water (such as Lake Washington or Puget Sound) similar to sloshing waves in a bathtub. Historically, Washington has had minor damage from seiches. Seattle fault and the Cascadia Subduction Zone earthquakes, however, have caused tsunamis. Washington is also at risk to tsunamis from distant earthquakes (see the Tsunamis Hazard Profile, Tab 7.1.7 for more information on their impacts).

In terms of economic impact, Washington ranks second in the nation after California among states susceptible to economic loss caused by earthquake, according to a Federal Emergency Management Agency (FEMA) study. The study predicts that the state faces a probable annualized economic loss of $228 million due to earthquake; average annualized loss is an equivalent measure of future losses averaged on an annual basis. Seattle is seventh and Tacoma is 22nd on a list of cities with more than $10 million in annualized earthquake losses.

Selected Earthquakes of Washington State, Magnitude 5.0 or Greater[17]

Date/Time (standard)	***Depth***	***Moment Magnitude***	***Location***
12/14/1872, 9:40 p.m.	0.0 km	6.8 (est.)	1.4 km SE of Chelan
01/11/1909, 3:49 p.m.	31.0 km	6.0	23.8 km NE of Friday Harbor
07/17/1932, 10:01 p.m.	0.0 km	5.7	15.6 km SE of Granite Falls
07/15/1936, 11:07 p.m.	0.0 km	6.1	8.1 km SSE of Walla Walla
11/12/1939, 11:45 p.m.	31.0 km	6.2	18.7 km S of Bremerton
04/29/1945, 12:16 p.m.	0.0 km	5.7	12.5 km SSE of North Bend
02/14/1946, 7:14 p.m.	25.0 km	5.8	28.4 km N of Olympia
04/13/1949, 11:55 a.m.	54.0 km	7.1	12.3 km ENE of Olympia
04/29/1965, 7:28 a.m.	57.0 km	6.5	18.3 km N of Tacoma
05/18/1980, 7:32 a.m.	2.8 km	5.7	1.0 km NNE of Mt St Helens
02/13/1981, 10:09 p.m.	7.3 km	5.2	1.8 km N of Elk Lake
01/28/1995, 7:11 p.m.	15.8 km	5.0	17.5 km NNE of Tacoma
07/02/1996, 8:04 p.m.	4.3 km	5.4	8.5 km ENE of Duvall
07/02/1999, 6:44 p.m.	40.7 km	5.8	8.0 km N of Satsop
02/28/2001, 10:54 a.m.	51.9 km	6.8	17.0 km NE of Olympia
06/10/2001, 5:19 a.m.	40.7 km	5.0	18.3 km N of Satsop

Impacts caused by the earthquakes shaded in the table above are described in narratives below.

Lake Chelan – December 14, 1872[18]

The magnitude 6.8 (est.) earthquake occurred about 9:40 p.m.

This earthquake was felt from British Columbia to Oregon and from the Pacific Ocean to Montana. It occurred in a wilderness area, which in 1872 had only a few inhabitants – local Indian tribes, trappers, traders, and military men. Because there were few man-made structures in the epicenter area near Lake Chelan, most of the information available is about ground effects, including huge landslides, massive fissures in the ground, and a 27-foot high geyser.

Extensive landslides occurred in the slide-prone shorelines of the Columbia River. One massive slide, at Ribbon Cliff between Entiat and Winesap, blocked the Columbia River for several hours. A field reconnaissance to the Ribbon Cliff landslide area in August 1976 showed remnants of a large landslide mass along the west edge of Lake Entiat (Columbia River Reservoir), below Ribbon Cliffs and about 3 kilometers north of Entiat. Although the most spectacular landslides occurred in the Chelan-Wenatchee area, slides occurred throughout the Cascade Mountains.

Most of the ground fissures occurred in the following areas: at the east end of Lake Chelan in the area of the Indian camp; in the Chelan Landing-Chelan Falls area; on a mountain about 12 miles west of the Indian camp area; on the east side of the Columbia River (where three springs formed); and near the top of a ridge on a hogback on the east side of the Columbia River. These fissures formed in several locations. Slope failure, settlements, or slumping in water-saturated soils may have produced the fissures in areas on steep slopes or near bodies of water. Sulfurous water was emitted from the large fissures that formed in the Indian camp area. At Chelan Falls, "a great hole opened in the earth" from which water spouted as much as 27 feet in the air. The geyser activity continued for several days, and, after diminishing, left permanent springs.

In the area of the epicenter, the quake damaged one log building near the mouth of the Wenatchee River. Ground shaking threw people to the floor, waves observed in the ground, and loud detonations heard. About two miles above the Ribbon Cliff slide area, the logs on another cabin caved in.

Damaging ground shaking of intensity VI extended to the west throughout the Puget Sound basin and to the southeast beyond the Hanford Site. Individuals in Idaho, Montana, Oregon, and Canada felt the earthquake. Aftershocks occurred in the area for two years.

State-Line Earthquake – July 15, 1936[19, 20]

The earthquake, magnitude 6.1, occurred at 11:05 a.m. The epicenter was about 5 miles south-southeast of Walla Walla. It was widely felt through Oregon, Washington and northern Idaho, with the greatest shaking occurring in Northeast Oregon. Property damage was estimated at $100,000 (in 1936 dollars) in this sparsely populated area.

The earthquake moved small objects, rattled windows, and cracked plaster in the communities of Colfax, Hooper, Page, Pomeroy, Prescott, Touchet, Wallula, and Wheeler; most of the impact and damage was in the Walla Walla area.

The earthquake alarmed residents of Walla Walla, many of whom fled their homes for the street. People reported hearing moderately loud rumbling immediately before the first shock. Standing pictures shook down, some movable objects changed positions, and doors partially opened. The earthquake was more noticeable on floors higher than the ground floor. It knocked down a few chimneys and many loose chimney brick; damaged a brick home used by the warden at the State Penitentiary that was condemned and declared unsafe; and damaged the local railroad station. Several homes moved an inch or less on their foundations, Five miles southwest of Walla Walla, the quake restored the flow of a weakened 600-foot deep artesian well to close to original strength; the flow had not diminished after several months.

Walla Walla residents reported about 15 or 20 aftershocks.

Olympia Earthquake – April 13, 1949[21, 22]

The earthquake, magnitude 7.1, occurred at 11:55 a.m. The epicenter was about eight miles north-northeast of Olympia, along the southern edge of Puget Sound. Property damage in Olympia, Seattle, and Tacoma was estimated at $25 million (in 1949 dollars); eight people were killed, and many were injured.

School buildings in widely separated towns were seriously damaged. Thirty schools serving 10,000 students were damaged; 10 were condemned and permanently closed. Chimneys on more than 10,000 homes required repair.

Water spouted from cracks that formed in the ground at Centralia, Longview, and Seattle. One new spring developed on a farm at Forest. Downed chimneys and walls were reported in towns throughout the area.

In Olympia, damage primarily was confined to the old part of the city and to areas of the port built on artificial fill. Most large buildings were damaged, including eight structures on the Capitol grounds. Many chimneys and two large smokestacks fell. Public utilities sustained serious damage; water and gas mains were broken and electric and telegraph services were interrupted. Breaks in 24 water mains temporarily closed the downtown business district.

In Centralia, the earthquake damaged 40 percent of the homes and businesses; two schools and a church were condemned; and the city's gravity-feed water system badly damaged. In Chehalis, damage occurred to four schools, city hall, the library, and county court house; the library was condemned. Seventy-five percent of the chimneys had to be replaced.

In Seattle, houses on filled ground were demolished, many old brick buildings were damaged, and chimneys toppled. One wooden water tank and the top of a radio tower collapsed. A 60-inch main broke at the city's water reservoir. Power failures occurred when swinging transmission lines touched, causing circuit breakers to trip. The gas distribution system broke at nearly 100 points, primarily due to damage caused by ground failure. Three damaged schools were demolished, and one rebuilt.

In Tacoma, many chimneys of older structures were knocked to the ground and many buildings were damaged. Water mains broke from landslides and settling in the Tideflats. Transformers at the Bonneville Power Administration substation were thrown out of alignment. Near Tacoma, a huge section of a 200-foot cliff toppled into Puget Sound three days after the earthquake; south of Tacoma, railroad bridges were thrown out of alignment. A 23-ton cable saddle was thrown from the top of a Tacoma Narrows bridge tower, causing considerable damage.

The earthquake was felt in Idaho, Montana, Oregon, and in British Columbia, Canada. Only one small aftershock occurred during the next six months.

Seattle-Tacoma Earthquake – April 29, 1965[23, 24]

The earthquake, magnitude 6.5, struck the Puget Sound area at 7:28 a.m. The epicenter was about 12 miles north of Tacoma at a depth of about 40 miles. The earthquake caused about $12.5 million (in 1965 dollars) in property damage and killed seven people.

A rather large area of intensity VII ground shaking, and small pockets of intensity VIII ground shaking in Seattle and its suburbs, including Issaquah, characterized the quake. Pockets of intense ground shaking, seen in damage such as fallen chimneys, were associated with variations in the local geology.

In general, damage patterns repeated those observed in the April 1949 earthquake, although that event was more destructive. Buildings damaged in 1949 often sustained additional damage in 1965.

Most damage in Seattle was concentrated in areas of filled ground, including Pioneer Square and the waterfront, both with many older masonry buildings; nearly every waterfront building experienced damage. Eight schools serving 8,800 students were closed temporarily until safety inspections could be completed; two schools were severely damaged. Extensive chimney damage occurred in West Seattle. The low-lying and filled areas along the Duwamish River and its mouth settled, causing severe damage at Harbor Island; slumping occurred along a steep slope near Admiral Way. A brick garage partly collapsed at Issaquah; one school was damaged extensively; and chimneys in the area sustained heavy damage. Many instances of parapet and gable failure occurred. Damage to utilities in the area was not severe as in 1949.

Buildings with unreinforced brick-bearing walls with sand-lime mortar were damaged most severely. Multistory buildings generally had slight or no damage. However, the Legislative Building once again was damaged and temporarily closed; government activities moved to nearby motels. Performance of wood frame dwellings was excellent, with damage confined mainly to cracks in plaster or to failure of unreinforced brick chimneys near the roofline.

Also damaged were two electric transmission towers in a Bonneville Power Administration substation near Everett; the towers each supported 230,000-volt lines carrying power from Chief Joseph Dam to the substation. Three water mains failed in Seattle, and two of three 48-inch water supply lines broke in Everett.

The earthquake was felt in Idaho, Montana, Oregon, and in British Columbia, Canada; little aftershock activity was observed.

Nisqually Earthquake – February 28, 2001[25, 26]

Federal Disaster #1361. Stafford Act disaster assistance provided to date – est. $155.9 million. Small Business Administration disaster loans approved - $84.3 million. Federal Highway Administration emergency relief provided to date - $93.8 million.

The earthquake, magnitude 6.8, struck the Puget Sound area at 10:54 a.m. The epicenter was below Anderson Island near the Nisqually River delta in Puget Sound about 50 miles south of Seattle and 11 miles northeast of Olympia. Ground shaking lasted about 45 seconds. Two minor aftershocks occurred near the epicenter of the main shock. This event was a slab earthquake; its depth calculated at 36.7 miles below the earth's surface in the Juan de Fuca plate.

The area of most intense ground shaking occurred along the heavily populated north-south Interstate 5 corridor, not around the epicenter. This was due to the amplification of the earthquake waves on softer river valley sediments. The earthquake was felt over a large area – from Vancouver, British Columbia, to the north; to Portland, Oregon, to the south; and Salt Lake City, Utah, to the southeast.

The six counties most severely damaged by the earthquake – King, Kitsap, Lewis, Mason, Pierce, and Thurston – were declared federal disaster areas one day after the event. Eventually, 24 counties received disaster declarations for Stafford Act assistance.

<u>Damages</u>

Various estimates have placed damage to public, business and household property caused by the Nisqually earthquake at from $1 billion to $4 billion. A 2002 study by the University of Washington funded by the National Science Foundation estimated the quake caused $1.5 billion in damages to nearly 300,000 households. A second study, also by the University of Washington funded by the Economic Development Administration of the U.S. Department of Commerce, estimated that 20 percent of small businesses in the region affected by the quake had a direct physical loss and 60 percent experienced productivity disruptions.

Damage to buildings, bridges and lifelines varied across the region, and depended on local soil conditions. Damage to buildings, lifelines and bridges was mainly nonstructural, with the majority of structural damage occurring in unreinforced masonry buildings.

Severe damage occurred in Olympia, at SeaTac Airport, and in south Seattle in the Pioneer Square and Sodo areas. Structures damaged included office buildings, residences, schools, hospitals, airport facilities and churches. Many damaged structures and surrounding areas were closed for various lengths of time following the earthquake.

Structural damage was primarily concentrated in older, unreinforced masonry buildings built before 1950, with some damage reported to wood-frame structures and reinforced concrete structures. In general, new buildings and buildings that had recently been seismically upgraded typically displayed good structural performance, but many still sustained non-structural damage.

In the major urban areas of King, Pierce and Thurston counties, 1,000 buildings were rapidly assessed immediately following the earthquake. Of these, 48 buildings were red-tagged, indicating serious damage, and 234 were yellow-tagged indicating moderate damage.

Damaged significantly were several state government buildings in Olympia, including the Legislative Building (the state's Capitol Building). The dome of the 74-year-old building sustained a deep crack in its limestone exterior and damage to supporting columns. There was non-structural damage throughout the building. Most other state agency buildings closed for one or more days for inspection and repair.

Lifeline systems generally performed well during the event. Water utilities reported minor structural damages; a number of wells in Eastern Washington reportedly went dry. A gas-line leak caused a fire and explosion when two maintenance workers were resetting an earthquake valve at a correctional facility near Olympia. Seattle City Light reported 17,000 customer power outages, and Puget Sound Energy reported 200,000 customers without power, but power was restored to most customers within a day. The volume of calls placed immediately after the earthquake overloaded landline and wireless communication systems.

Transportation systems suffered more damage. Seattle-Tacoma International Airport closed immediately because its control tower was disabled. A temporary backup control tower allowed reopening of the airport to limited traffic several hours after the quake. King County Airport (Boeing Field) suffered serious cracking and gaps on the runway due to soil liquefaction and lateral spreading. The main runway reopened for business a week later.

While the area's overall road network remained functional, many highways, roads, and bridges were damaged. Several state routes and local roadways closed due to slumping and pavement fractures. The quake badly damaged the Alaskan Way Viaduct (State Route 99), a major arterial in Seattle. Temporary repairs made the structure usable; various proposals to permanently repair or replace it run in the billions of dollars. Two local bridges closed due to significant damage – the Magnolia Bridge in Seattle and the Fourth Avenue Bridge in Olympia.

There was minor damage to dock facilities in both Tacoma and Seattle, but not extensive enough to interrupt commercial port services.

The state's dams fared well during the earthquake. Of the 290 dams inspected by state engineers, only five had earthquake-related damage; these dams were susceptible to damage due to their poor construction and weak foundations. Dams controlled or regulated by the Federal Energy Regulatory Commission, the Bureau of Reclamation, or the U.S. Army Corps of Engineers, were not damaged.

Damage to residential structures came in a variety of forms, from severe mudslide destruction of entire homes to breakage of replaceable personal property. A 2002 University of Washington study on residential loss estimated nearly 300,000 residential units – about one of every four Puget Sound households – experienced $1.5 billion in damage. The study indicates that structural damage to roofs, walls and foundations accounted for nearly two-thirds of losses, followed by chimney damage, and damages to nonstructural elements and household contents.[27]

Jurisdictions Most Vulnerable

For the State Hazard Mitigation Plan, primary factors used to determine which counties are most vulnerable to future earthquakes are:

- The Annualized Earthquake Loss, as calculated by HAZUS.
- The Annualized Earthquake Loss Ratio, as calculated by HAZUS.

Counties considered most at risk are those with an Annualized Earthquake Loss of at least $1 million or with an Annualized Earthquake Loss Ratio equal or greater than the state's ratio of 0.05. Twenty-one counties meet one of these two criteria.

Additionally, Chelan, Kittitas, and Walla Walla Counties, which have greater seismic risk than most counties in Eastern Washington but do not have building stock to meet the above criteria, have been added to the list of jurisdictions most vulnerable at the advice of state and federal geologists and seismologists with expertise in earthquakes in Washington.

Other factors, including the size of potentially vulnerable populations and age of the housing stock, also play a part in determining which counties are most vulnerable. Factors considered include:

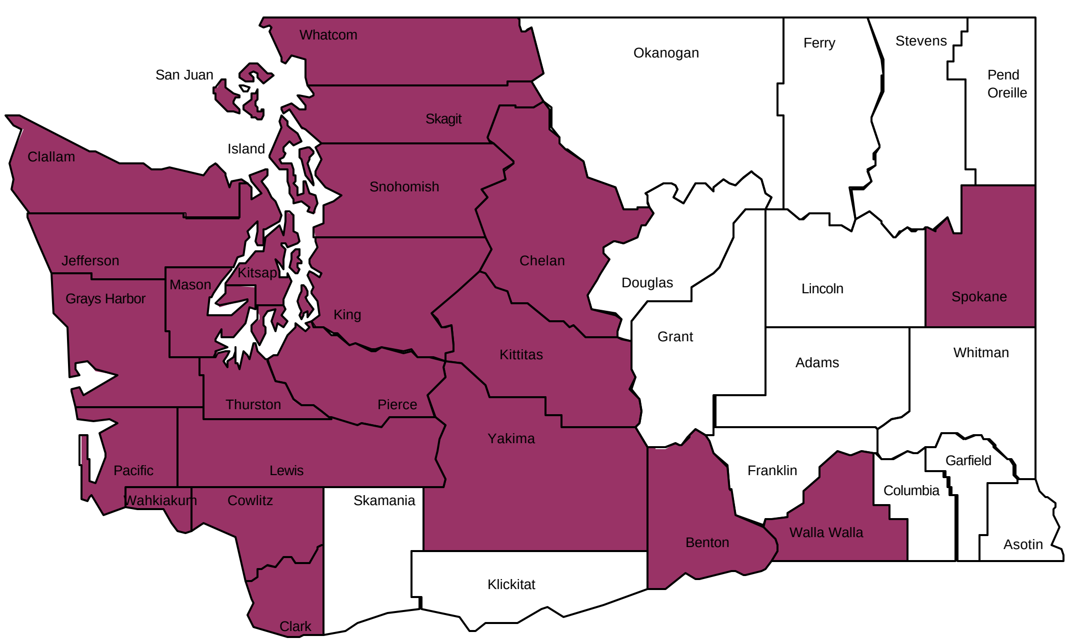
- The percentage of the total population of each of the following groups: people who do not speak English as their primary language, individuals with disabilities, senior citizens, people living in poverty, and children in school (kindergarten through 12th grade.

- The percentage of housing stock built before 1960.

Based on these factors, the following counties are at greatest risk and most vulnerable to earthquakes:

Benton	Chelan	Clallam	Clark	Cowlitz	Grays Harbor
Island	Jefferson	King	Kitsap	Kittitas	Lewis
Mason	Pacific	Pierce	San Juan	Skagit	Snohomish
Spokane	Thurston	Wahkiakum	Walla Walla	Whatcom	Yakima

Counties Most At-Risk and Vulnerable to Earthquake



Annualized Earthquake Loss and Annualized Earthquake Loss Ratio

The Annualized Earthquake Loss measure addresses the two key components of seismic risk: the probability of ground motion occurring in the study area, and the consequences of the ground motion. The parameters used in computing the loss include those associated with direct economic losses to buildings (repair and replacement of structures, damage to contents and to inventory) and income (relocation costs, business income and wages paid, loss of rental income). The annualized loss represents a long-term average.

The Annualized Earthquake Loss Ratio measure addresses seismic risk in relation to the value of the building inventory in the study area. The annualized ratio represents the Annualized Earthquake Loss as a fraction of the replacement value of the building inventory. It is a measure of relative risk between regions and allows for direct comparison across different geographic units.

Results of both measures are displayed for all counties in Table 1, below.

A note about HAZUS loss estimates used in this profile: The estimates of social and economic impacts developed by HAZUS were produced using loss estimation methodology software based on current scientific and engineering knowledge. There are uncertainties inherent in any loss estimation technique. Therefore, there may be significant differences between the modeled results and the actual social and economic losses following a specific earthquake. These results can be improved using enhanced inventory, geotechnical, and observed ground motion data.

Table 1. Annualized Earthquake Loss Computed by HAZUS

County	Annualized Earthquake Loss	Loss Ratio	County	Annualized Earthquake Loss	Loss Ratio
King	$105,571,000	0.07	Walla Walla	$753,000	0.02
Pierce	$28,398,000	0.06	Chelan	$698,000	0.01
Snohomish	$20,913,000	0.06	San Juan	$599,000	0.05
Clark	$11,463,000	0.06	Kittitas	$498,000	0.02
Kitsap	$9,212,000	0.07	Franklin	$494,000	0.02
Thurston	$6,732,000	0.05	Douglas	$385,000	0.02
Grays Harbor	$5,943,000	0.11	Klickitat	$343,000	0.03
Whatcom	$4,987,000	0.04	Skamania	$224,000	0.04
Cowlitz	$4,250,000	0.07	Whitman	$218,000	0.01
Lewis	$3,861,000	0.08	Okanogan	$204,000	0.01
Yakima	$3,609,000	0.02	Wahkiakum	$170,000	0.07
Skagit	$2,874,000	0.04	Stevens	$157,000	0.01
Clallam	$2,863,000	0.06	Adams	$120,000	0.01
Spokane	$2,743,000	0.01	Asotin	$86,000	0.01
Island	$2,448,000	0.05	Pend Oreille	$67,000	0.01
Mason	$2,069,000	0.06	Lincoln	$58,000	0.01
Pacific	$1,989,000	0.10	Ferry	$45,000	0.01
Benton	$1,726,000	0.02	Columbia	$33,000	0.01
Jefferson	$1,175,000	0.06	Garfield	$21,000	0.01
Grant	$906,000	0.02	*Washington State*	*$228,895,000*	*0.05*

Data Sources: Washington Emergency Management Division HAZUS run July 8, 2003, using Level 1 analysis adjusted and default ground shaking and soils data, and advice of state and federal geologists and seismologists. Counties most vulnerable to earthquakes are shaded.

Socio-Economic Factors

The ability to prepare for and recover from a disaster varies among population groups. Research on various population groups and disasters found that some population groups are more vulnerable to the impact of a hazard event for a number of reasons. These population groups include people who do not speak English as their primary language, individuals with disabilities, senior citizens, people living in poverty, and children in school (pre-school through 12th grade).

- People who do not speak English as their primary language often have a language or culture barrier that prevents them from preparing for a disaster, responding to a hazard event, or applying for assistance after a disaster.

- People with disabilities often have difficulties preparing in advance for a disaster because of hearing, sight, mobility, or mental impairments. This makes them less able to prepare in advance and more vulnerable to the impact of a hazard event than able-bodied individuals.

- Senior citizens may have trouble preparing for a disaster or recovering after a hazard event because some do not qualify for loans due of limited means, they have disabilities that limit their ability to prepare, or they may become disabled because of a hazard event.

- The amount of money people have influences what type of housing they live in, whether they can engage in mitigation actions, and how long it takes to recover. People of limited financial means may not have money for preparedness and mitigation activities, and often live in older housing that is more vulnerable to a hazard event.

- The number of children attending school is a concern because many of the school buildings they spend considerable time in each day are older and potentially more vulnerable to the effects of disaster.

Counties with significant numbers of potentially vulnerable people are at greater risk to the impact of a disaster caused by an earthquake than counties with smaller populations from these groups.

Another factor considered in the vulnerability of counties to earthquake is age of their housing stock. The year housing was built is important for mitigation; the older a home is, the greater the risk of damage from natural disasters. Housing most at risk is that built before 1960.

See Table 2, below.

Table 2. Socio-Economic Factors Compared to State Average

County	Non-English Speaking	Disabled	Over Age 65	Poverty	K-12 Students	Housing Older Than 40 Years
King	18.4%	15.1%	10.5%	6.4%	16.6%	33.5%
Pierce	11.8%	20.4%	10.2%	10.5%	20.3%	28.1%
Snohomish	12.2%	16.7%	9.1%	6.9%	20.2%	18.0%
Clark	11.5%	17.8%	9.5%	9.1%	20.5%	17.1%
Kitsap	8.3%	18.1%	10.6%	8.8%	20.2%	23.6%
Thurston	9.2%	18.9%	11.4%	8.8%	19.5%	16.9%
Grays Harbor	6.4%	24.0%	15.4%	16.1%	19.8%	41.8%
Whatcom	9.2%	14.3%	11.6%	14.2%	17.7%	26.0%
Cowlitz	6.0%	22.0%	13.3%	14.0%	19.8%	38.5%
Lewis	6.4%	24.2%	15.5%	14.0%	20.1%	36.9%
Yakima	31.8%	24.1%	11.2%	19.7%	23.8%	37.3%
Skagit	11.7%	18.2%	14.6%	11.2%	17.7%	30.6%
Clallam	6.3%	23.0%	21.3%	12.5%	17.1%	23.3%
Spokane	6.6%	18.9%	12.4%	12.3%	19.3%	41.3%
Island	8.2%	16.5%	14.3%	7.0%	18.6%	17.0%
Mason	6.3%	23.1%	16.5%	12.2%	18.5%	16.6%
Pacific	8.2%	26.3%	22.6%	14.2%	17.8%	36.2%
Benton	14.2%	17.9%	10.3%	10.3%	22.3%	26.0%
Jefferson	4.0%	16.3%	21.1%	12.5%	15.1%	21.3%
San Juan	4.9%	16.4%	19.0%	9.2%	15.5%	14.0%
Wahkiakum	4.3%	23.0%	18.5%	8.1%	18.0%	42.2%
Walla Walla	16.2%	20.4%	14.8%	15.1%	19.1%	48.3%
Chelan	19.6%	18.4%	13.9%	12.4%	21.5%	35.0%
Kittitas	7.7%	18.1%	11.6%	19.6%	15.6%	32.6%
Washington State	*14.0%*	*17.7%*	*11.2%*	*10.6%*	*19.1%*	*29.4%*

Source: U.S. Census Bureau, Profile of Selected Social Characteristics: 2000, and Profile of Housing Characteristics: 2000. Counties listed by ranking of annualized loss. Numbers expressed as percentage of total population or total housing stock of county. Shaded cells indicate percentage equal to or greater than Washington State as a whole.

State Agency Structures At Risk **PRELIMINARY ASSESSMENT**

Number and Function of Buildings	No. of Affected Staff / Visitors / Residents	Approx. Value of Owned Structures	Approx. Value of Contents All Structures
Total at-risk buildings: State agencies participating in this plan identified 2,243 facilities as being potentially at risk to earthquake.	256,065	$10,736,576,814	$4,972,426,507

Function of at-risk buildings: Included in the state facilities potentially at-risk to earthquakes are the following:

- Buildings of the State Capitol Campus, and nearby headquarters offices of nearly all agencies of state government.
- Main campuses of Western Washington University and the University of Washington; and the marine laboratories they operate.
- Harborview Medical Center, Children's Hospital, and the UW Hospital, all on or near the main University of Washington campus.
- University of Washington branch campuses in Bothell and Tacoma.
- Campuses of Big Bend Community College, Everett Community College, Seattle Central Community College, and South Puget Sound Community College.
- A campus leased to the federal government used for a Job Corps Center.
- State schools for the blind and deaf.
- Campuses of Francis Haddon Morgan, Rainier School, Western State Hospital, Eastern State Hospital, Fircrest School, Yakima Valley School and Lakeland Village for individuals with physical and mental disabilities.
- Campuses of Maple Lane School, Green Hill School, Naselle Youth Camp, and Echo Glen Children's Center for juvenile offenders.
- Special Confinement Center for sexual offenders.
- Regional headquarters, local detachments, highway weigh scales, and communication facilities of the Washington State Patrol.
- Hundreds of general office and client service offices, primarily in Western Washington, that include those serving individuals and families on public assistance, providing employment and training services, driver licensing, and liquor sales.

More detailed narratives on facilities at risk can be found in the Region profiles, Tab 7.2.1 – Tab 7.2.9.

Eleven state highways considered emphasis corridors because of their importance to movement of people and freight are potentially at risk to earthquake:

1. Interstate 5
2. Interstate 90
3. Interstate 405
4. U.S. Highway 2
5. U.S. Highway 12
6. U.S. Highway 20
7. U.S. Highway 101
8. State Route 14

9. State Route 16
10. State Route 18
11. State Route 167

Additionally, ferry landings in Anacortes, Bainbridge Island, Bremerton, Clinton, Fauntleroy, Keystone, Mukilteo, Port Townsend, the San Juan Islands, Seattle, Southworth, Tacoma, and Vashon Island are potentially at risk because of their construction on poor soils in shoreline areas.

Total at-risk critical facilities: State agencies participating in this plan identified 818 critical facilities as being potentially at risk to earthquake.	85,121	$3,827,149,630	$2,818,375,234

Function of at-risk critical facilities: Included in the state facilities potentially at-risk to earthquakes are the following:

- Buildings of the State Capitol Campus, and nearby headquarters offices of nearly all agencies of state government.
- More than 100 buildings on the campuses of Western Washington University and the University of Washington, and marine laboratories they operate.
- Buildings on the campuses of Everett Community College, Seattle Central Community College, and South Puget Sound Community College.
- A campus leased to the federal government used for a Job Corps Center.
- State schools for the blind and deaf.
- Regional headquarters, local detachments, highway weigh scales, and communication facilities of the Washington State Patrol.
- Residential campuses and hospitals for adults with physical and mental disabilities, including Western State Hospital and the Rainier School.
- Hundreds of general office and client service offices, primarily in Western Washington, that include those serving individuals and families on public assistance, providing employment and training services, driver licensing, and liquor sales.

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[5] Current approximate recurrence rates of M9.0 Cascadia Subduction Zone, M=6.5 Seattle Fault, Deep M=6.5, and random shallow M=6.5 earthquakes provided by Arthur D. Frankel, U.S. Geological Survey, in an oral presentation at the *Workshop On Geologic Research In The Seattle Area*, University of Washington, October 20, 2003.

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[15] Ruth Ludwin, *Earthquake Prediction*, Washington Geology, vol. 28, no. 3, page 27, Washington Department of Natural Resources, Division of Geology and Earth Resources, May 2001.

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